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TRIP REPORT
INTERNATIONAL CONGRESS ON APPLICATIONS OF LASERS AND ELECTRO-OPTICS
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Topics covered at the International Congress on Applications of Lasers and Electro-Optics (ICALEO) include developments in alternative laser sources, very high power CO_2 laser processing, both of which could lead to more energy efficient laser materials processing. Information was also gathered on optical techniques for laser surface modification, the cutting and welding of non-ferrous metals, and on the economics of the laser welding of automotive parts.

1.0 BACKGROUND

The International Congress on Applications of Lasers and Electro-Optics (ICALEO) is an annual event that comprises four conferences, dealing with laser materials processing, medical applications, flow diagnostics and optical sensing. For the past few years I have attended the laser materials processing conference and have found it to be a stimulating gathering of experts in the field from around the world.

As in the past, the conference featured a balanced representation from Europe, Japan and North America in the 39 papers presented and in the more than 100 attendees. The

presentations covered a broad spectrum of topics, including cutting, drilling, welding and surface treatment. Of particular interest at this year's meeting were papers dealing with very high power (15-25 kW) CO_2 laser processing and the search for alternatives to the CO_2 laser as a materials processing source. Both of these developments promise improved energy conservation in the form of higher electrical efficiencies for materials processing since high power CO_2 lasers are twice as efficient as lower powers and alternatives such as the CO laser and the chemical laser have typically twice the efficiency of the highest power CO_2 lasers. These and other highlights are described in this report.

2.0 OVERVIEWS OF LASER MATERIALS PROCESSING

Three of the leading lights in laser materials processing presented summaries of recent developments in North America, Europe and Japan. It was evident that most of the latest advances had taken place outside North America.

The North American and Japanese overviews were rather mundane presentations describing various specific projects, but the European presentation, by Prof. William Steen of the University of Liverpool, was lively and stimulating. Perhaps this is a reflection of the current state of laser materials processing in Europe. There is a strong spirit of cooperation among the researchers in the various countries; this has undoubtedly arisen out of such pan-European networks as BRITE (Basic Research in Industrial Technology for Europe) and EUREKA (European Research Cooperation Agency). The result is that most European scientists belong to one or more collaborative research teams which may span several countries. Within the European community Germany stands out for its huge investment in several laser materials processing centres of excellence, most of which were represented at the conference. It is noteworthy that two of the major high power laser manufacturers (Rofin-Sinar and Trumpf) are based in Germany. Although the European market for laser systems is growing at 11 to 20% per year above inflation, Prof. Steen cautioned that training of students in laser materials processing is lagging behind and that manpower shortages may impede future growth.

3.0 DEVELOPMENTS IN ALTERNATIVE SOURCES TO THE CO_2 LASER

While the 10.6 μm CO_2 laser remains the workhorse of laser materials processing, there is an interest in lower wavelength sources, which have two main advantages. Their energy can be delivered by optical fibres and the coupling of their energy to most metals is enhanced. Developments in three alternative lasers, Nd:YAG (1.06 μm), CO (5 μm) and the oxygen-iodine chemical laser (1.3 μm) were presented.

3.1 Nd:YAG Laser

A Japanese company, NEC, reported on the development of a commercial 2 kW YAG laser consisting of six cascaded cavities each with a 15 cm long rod of 8 mm diameter. The laser can be operated cw (continuous wave) or pulsed at up to 150 pps. The divergence of the multi-mode output beam is 25 to 30 mrad, an order of magnitude larger than for CO_2 lasers in this power range. A 0.6 mm diameter quartz optical fiber delivers more than 90% of the output power to remote locations. In preliminary applications tests with this laser, 4 mm thick mild steel has been welded at 0.6 m per min. Similar performance can be achieved with a CO_2 laser in this power range without, however, the capability of fiber optic beam delivery.

In the US, a new company (Laser Technology Associates) has been formed by former GE employees to build and market the long awaited slab YAG lasers. In this design the optical beam makes multiple bounces within the YAG material between two parallel faces of the slab. Use of a slab geometry rather than the traditional rod holds the promise of better beam quality, thereby yielding a higher focused energy density and greater processing speeds. GE patented the slab design in 1972 but failed to develop it. With the patent expiring this year, the new company is planning to build a prototype 500 W slab YAG laser (50 J at 10 pps) and market it as a tool with enhanced materials processing capabilities due to its low beam divergence (< 1 mrad) and high energy density. It was evident at the conference that the industry is adopting a wait-and-see attitude because of the history of undelivered promises regarding this technology.

3.2 CO Laser

As first described at last year's ICALEO meeting/1/, the Japanese are developing a CO laser at 5 μm targeted at the cutting of thick steels, specifically for nuclear power plant decommissioning. This year's meeting presented further progress towards this goal.

Mitsubishi has built a prototype 5 kW laser which may be commercialized if the potential market is large enough. The design is scalable to higher powers; by 1991 they expect to have a 20 kW device which could be eventually raised to the 40 kW level required to cut steel at the target thickness of 30 cm. An electrical efficiency of 20% is typical.

Test cuts with the 5 kW laser have been performed on stainless steel specimens up to 8 cm in thickness. The effect of focus position and assist gas on cutting speed and cut quality were investigated. There is also interest in exploring the use of CO lasers for welding applications.

3.3 Chemical Oxygen-Iodine Laser (COIL)

In spite of its advantages over the CO_2 laser, the CO laser has certain drawbacks as a materials processing tool, namely the low operating temperature (200 K), the rapid consumption of CO in the discharge and the less than optimum transmission of optical fibres at 5 μm. Because of this, the Japanese Industrial Research Institute, which spearheaded the CO laser development, is currently investigating a chemical oxygen-iodine laser (COIL), chosen primarily for its operating wavelength (1.3 μm), which is close to the optimum for fiber optic transmission.

The COIL is a simple laser in which chlorine, hydrogen peroxide and sodium hydroxide react to form excited oxygen which transfers its energy to iodine atoms to populate the upper state of the lasing transition. This laser has an inherently good beam quality because of its low operating pressure (a few torr). Recent progress towards the realization of an industrial chemical laser includes the demonstration of more than 1 kW output power and greater than 40% chemical efficiency. However, much development remains to be done in the areas of improved reliability and lifetime, pulsed operation and reduced cost. An industrial partner, Kawasaki, is building a prototype COIL which may be the forerunner of a commercial product.

4.0 VERY HIGH POWER CO_2 LASER PROCESSING

The majority of CO_2 lasers for materials processing are in the 500 W to 1.5 kW range. As noted at last year's ICALEO/1/, there are now many applications in the multi-kilowatt range (2 to 10 kW). However, at very high powers (>10 kW) there are relatively few lasers in use around the world. The maximum power available commercially is 25 kW, represented by a single supplier, United Technologies Industrial Lasers (UTIL) in Connecticut, which sells the unit for $1 M.

This situation represents a good opportunity for a laser job shop specializing in very high power laser materials processing. Within the past year, the first such enterprise has been started up in Pennsylvania. The company, Stardyne, presented two papers at the conference describing their capabilities.

Stardyne has taken over a former US Steel foundry and has housed it with two UTIL 25 kW CO_2 lasers, each of which accesses several work cells via beam transfer modules. The facility is capable of welding, cladding or cutting components up to 35 feet high and up to 15 tons in weight. Stardyne is closely affiliated with Penn State University's Applied Research Laboratory and UTIL's laboratory, which keeps them in touch with the latest development such as robotic delivery of high power laser beams.

Many of Stardyne's initial projects have been in defense applications, such as the thick section cutting and welding of pipe up to 2.5 cm thick for the navy shipyards and the cladding of aircraft carrier components. They have also been engaged in refurbishing equipment for nuclear power plants. The example described was the cladding of a 4.6 m long, 7.5 cm diameter worn shaft at a cost much less than the cost of a new shaft. They will be sending me details of their utility applications.

There may be an opportunity for Ontario Hydro to make use of these unique services. Surprisingly, the costs of this high power laser job shop are no higher than those of conventional job shops ($100 to $250 per hour), partly because of federal government start-up funding and partly because of low labor costs.

The manager of UTIL's Industrial Laser Division presented a paper extolling the virtues of high power lasers compared to lower powers. On a dollars per watt basis, the capital cost of a 25 kW CO_2 laser is one half of the cost of a 1 kW laser and the floor space per kW is also significantly lower. Processing at higher powers frequently results in improved productivity, for example in a higher quality weld bead. This was supported by data on the cost per hour of producing various parts which in many cases showed significant advantages to processing at higher powers. There is also an advantage in electrical efficiency, with 25 kW CO_2 lasers having wall-plug efficiencies of 10% compared to 5 to 6% for 1 to 2 kW CO_2 lasers.

5.0 PROCESSING OF NON-FERROUS METALS

The great majority of the applications of CO_2 lasers to the processing of metals deal with ferrous metals in the form of carbon steels and stainless steels. The non-ferrous metals such as aluminum and copper are typically very reflective at 10.6 μm, making it difficult to couple sufficient energy from the laser source to initiate the melting or vaporization process. In the past few years, progress has been made in processing these materials and several papers at the conference dealt with advances in this area. Note that one of the selling points of our PRC laser is its ability to process copper and aluminum because of its excellent beam quality and high focused energy density.

A paper from Stuttgart University described a study of the cutting of copper, silver, brass, aluminum and magnesium using a 1.5 kW CO_2 laser. An analysis of the results showed that the cutting speed is dominated by two material specific factors, the power threshold or minimum power for total separation, which is governed by the thermal conductivity and absorptivity of the material, and the shape of the cutting speed vs power curve, which is determined by the melting point, density and absorptivity. In a somewhat surprising result, at powers significantly above the power threshold, the cutting speed for aluminum and brass is greater than that of steel, although for copper the speeds are always lower.

A second German paper focused on the cutting of aluminum alloys using oxygen assist gas at various pressures. The dross was reduced for both Al Li and Al Zn Mg Cu alloys as the gas pressure was increased from 1 to 10 bar. Mechanical and corrosion tests of laser cut samples demonstrated that the cut quality is adequate for aerospace applications only if a post-processing heat treatment is applied to eliminate pitting corrosion in the heat affected zone.

The welding of these materials was also reported. The Applied Research Laboratory at Penn State University has welded 2.5 cm thick sections of aluminum alloys 7039 and 5083 at 1 m per min and 1.3 cm thick samples of 2090 alloy at 2 to 4 m per min using 8 to 10 kW of CO_2 laser power. The weld profiles showed some undercut due to the absence of filler material but demonstrated minimal porosity and no cracking. However, microhardness profiles showed some softening of the weld zone for all three alloys. A second paper from the same group included data on the welding of copper alloys. Plates of 1.3 cm thickness were welded at 1.3 m per min using 8 to 10 kW of CO_2 laser power.

A scheduled paper on the Nd:YAG laser welding of copper was not presented but was included in the conference proceedings. Japanese researchers have investigated the joining of a beryllium-copper alloy to pure copper in 2 mm thick plates using 120 W of YAG laser power. The weld was poor unless the pure copper was covered with 10 μm-thick nickel plating and heated for one hour at 1000C prior to welding. Based on discussions with Lumonics over the past year, it should be possible to weld such samples without the need for plating or preheating by using higher YAG powers (>1 kW). IBM Canada has an interest in the laser welding of copper and I have recently put them in contact with Lumonics to have test runs performed on their copper samples/2/.

6.0 SURFACE TREATMENT

6.1 Improved Energy Coupling

A second paper from Stuttgart University described methods of improving the energy coupling in surface treatment applications. One of these involves Fresnel absorption, i.e. increasing the angle of incidence with the polarization parallel to the plane of incidence gives increased absorptivity. The second method makes use of the high absorptivity of deposited powders in cladding or alloying applications. Each of these techniques increases the coupling by a factor of three or four.

This paper also described preliminary work on optimization of the laser beam's energy distribution for surface hardening, which may lead to a reduction in the energy consumption compared to the conventional scanner or optical integrator approaches.

6.2 Optical Hardware

During the past year we have been engaged in negotiations with Two-Six Inc. to build an optical integrator (kaleidoscope) to even out the laser beam's energy distribution for surface treatment applications. The stimulus for this contact was a discussion with Stan Ream at last year's ICALEO/1/. At this year's meeting I had further discussions with Mr. Ream, who suggested an alternative method of beam integration, in the form of two segmented cylindrical lenses oriented at right angles to each other. Such a design may be less expensive to build than a kaleidoscope and should provide equivalent performance. According to Glen Sherman, chairman of Laser Power Optics, his company may be able to build such optics for us.

I spoke to David Belforte, editor of Industrial Laser Review, about a recent reference in his magazine to computer-synthesized optical elements that convert the laser output into a desired beam profile. This technology was developed in the USSR and is being marketed by a German company. Two-Six has contacted this company and will be obtaining samples of these optical elements to test their performance. This may represent another alternative to the relatively expensive (US $15K) kaleidoscope.

7.0 LASER WELDING OF AUTOMOTIVE PARTS

A paper from Japan on the economics of laser welding for automotive parts manufacturing was one of the few to deal with the question of the costs of laser processing and how these compare to those of competing technologies. Two applications were considered. In the first, a shaft was laser welded to a plate to form a rotator and the cost compared to electron-beam and resistance welding. At low production rates the total costs of laser and electron-beam welding were comparable but at 160,000 units per month the laser costs were 20% lower. In the second application, pulley welding, the costs of laser welding were 10% lower than electron-beam. In both cases the electron-beam's lower operating cost was not enough to overcome its higher capital costs.

8.0 SUMMARY

As in previous years, the ICALEO laser materials processing conference provided a wealth of information on recent developments in high power lasers and their applications to cutting, welding and surface treatment. Highlights of this year's meeting were developments in alternative sources to the CO_2 laser, very high power CO_2 laser processing and the processing of non-ferrous metals.

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